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CENOZOIC PALEOGEOGRAPHY OF WESTERN NEBRASKA

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ABSTRACT

The Cenozoic strata of western Nebraska are an extensive sequence of continental deposits that extend eastward from the Hartville, Laramie, and Front Range uplifts and southeast from the Black Hills. The oldest Cenozoic sediments (Chadron Formation, White River Group) are Early Oligocene alluvial valley fills. Subsequent to filling of these drainages and continuing for about the next 7 m.y., landscape development in western Nebraska was dominated by eolian deposition of tremendous volumes of rhyolitic volcanic ash derived from western eruptions. A plain of low relief, with only an occasional narrow drainage heading in the western highlands, was maintained during most of this period. Uplift in the Rocky Mountains and Great Plains (pre-Gering Formation, Arikaree Group) caused erosion and brought epiclastic detritus into the area about 28 m.y. ago. Eolian sediment consisting mostly of pyroclastic detritus continued building the plains during and after Gering alluvial deposition until about 19 m.y. ago when Arikaree deposition ceased. About this time, western volcanic activity declined for several million years and was followed by a marked decrease in the volume of rhyolitic volcanism for the remainder of the Cenozoic. At the end of Arikaree deposition in western Nebraska, a major pulse of erosion (pre-Runningwater Formation, Ogallala Group) was followed by a fundamental change in depositional style and landscape evolution, characterized by a heterogeneous mixture of epiclastic valley fills. Sands and gravels from Rocky Mountain sources were first deposited in a major valley in the northern half of the area and later in valleys to the south. Episodic regional and local structural movements influenced the size and position of many Ogallala valleys. For the past 5 m.y. degradation, in response to major regional uplift, has greatly exceeded aggradation as the dominant factor affecting landscape evolution in western Nebraska.

INTRODUCTION

This report is a general outline of successive changes in the Cenozoic landscape of western Nebraska. It also presents some new interpretations on the role of structure in influencing regional depositional and erosional patterns in this area. Lugn and Lugn (1956) presented the first attempt at a regional synthesis of Tertiary paleogeography of Nebraska. Since 1956, many outcrop studies and paleontologic investigations have modified understanding of the geology of western Nebraska. In addition, analysis of a large amount of subsurface information has provided new insights into the stratigraphy of the region and furnished a data base for paleogeographic interpretations which would be impossible to achieve from outcrop studies alone.

The surface of Cenozoic rocks in the study area forms an eastward sloping plain from the Laramie Range-Hartville Uplift in Wyoming (Fig. 1) that has been deeply eroded in the North Platte River valley and along the Pine Ridge (Fig. 2). Dune sand covers most of the east central part of the area. Subsurface data used in this report came from electric logs of approximately 11,600 oil and gas tests and from samples and electric logs of about 500 test holes

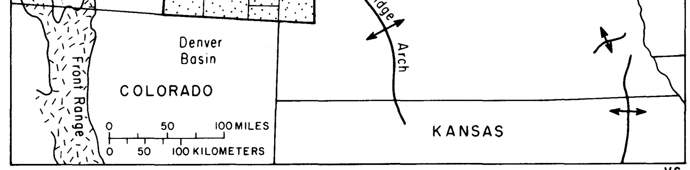


Figure 1. Index map of study area and major regional uplifts and basins.

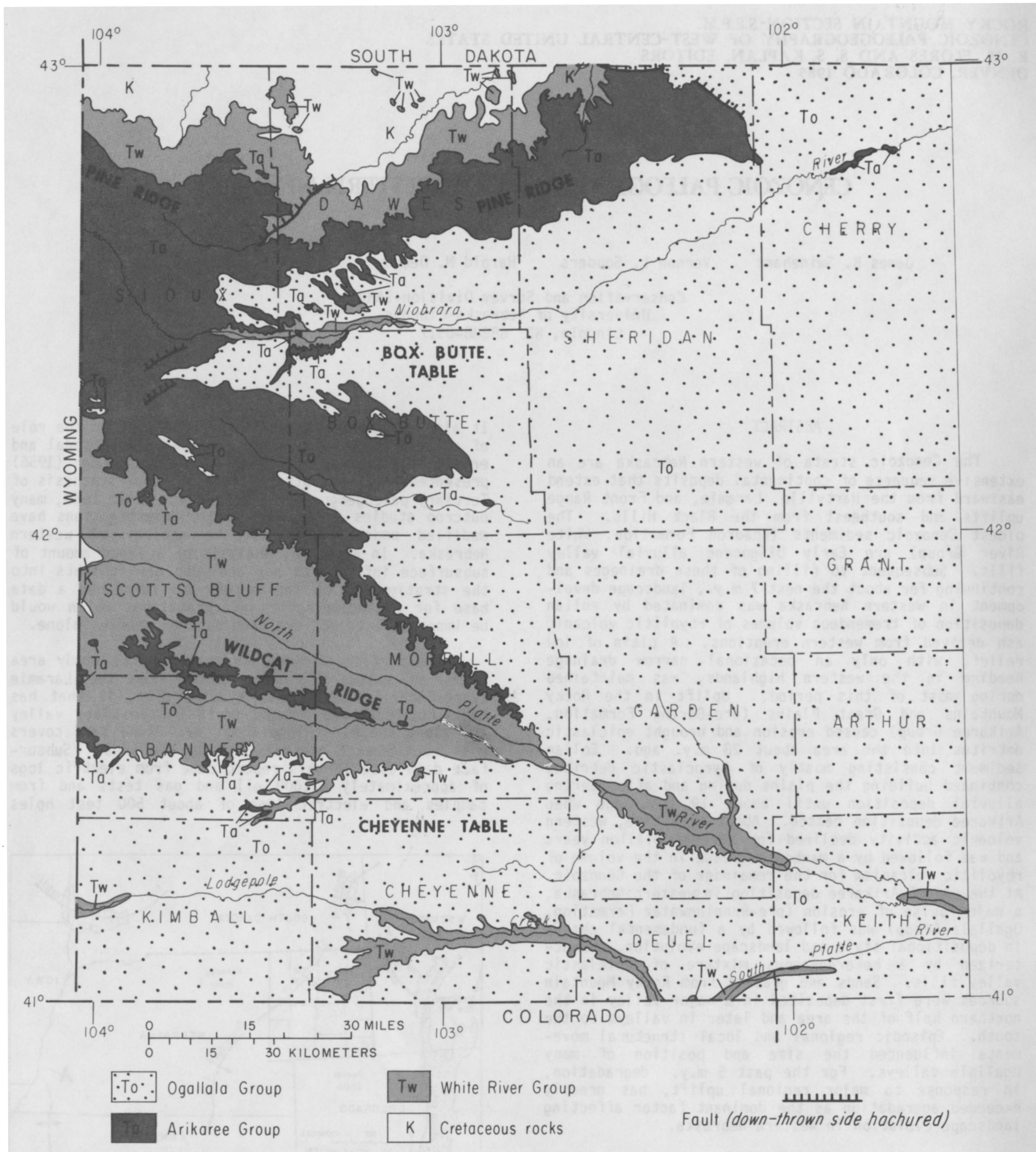


Figure 2. Generalized geologic map of western Nebraska. Post-Ogallala rocks (Pliocene and younger) not shown. Cretaceous rocks refer to Pierre Shale in the north and Fox Hills Sandstone in Scotts Bluff County. Only known faults with apparent throws in excess of 100 ft (30 m) are shown.

drilled by the Conservation and Survey Division and its cooperators (Fig. 3). Drillers' logs of irrigation wells were also utilized.

GENERAL STRATIGRAPHY AND LITHOLOGY OF CENOZOIC ROCKS

Rocks of the Paleocene or Eocene series have not been identified in western Nebraska and the oldest Cenozoic rocks known belong to the Oligocene Chadron Formation (Fig. 4 and Table 1). An oxidized zone (the Interior Paleosol) occurs throughout much of western Nebraska on truncated Cretaceous and Jurassic rocks and represents a pre-Chadron and Chadron weathering horizon. The Cenozoic deposits of western Nebraska can be divided into two major packages: an older, relatively homogeneous set of fine-grained volcaniclastic rocks (White River and Arikaree groups, Table 2) primarily of eolian origin and a younger, coarser grained and more heterogeneous set (Ogallala Group and younger rocks, Table 2) composed mostly of epiclastic debris of alluvial origin. Deposition for much of the White River and Arikaree was remarkably continuous over large areas (Fig. 5). The Ogallala and younger rocks consist of a much less continuous set of complex valley fills of widely variable geometries and lithologies.

White River Group

Traditionally, the White River Group has been divided into three stratigraphic units in western Nebraska, the Chadron, Orella, and Whitney (Schultz and Stout, 1955). We recognize three depositional sequences in the group, based on subsurface data supplemented by outcrop studies, which do not correspond to the above mentioned units. The depositional sequences (Fig. 6) consist of the following stratigraphic intervals (oldest to youngest): 1) the base of the Chadron Formation to the unconformity in the Orella Member of the Brule Formation; 2) the unconformity to the top of the Whitney Member of the Brule Formation; and 3) the Brown Siltstone beds of the Brule Formation (a new informal unit). This upper sequence previously was not recognized in Nebraska, or was either identified as various units of the Arikaree Group or included in the Whitney Member. From southwest to northeast, these sequences become more difficult to distinguish because of lack of control, absence of marker beds and increasing lithologic similarity.

Arikaree Group

The stratigraphy of the Arikaree Group has been the subject of much controversy since the 1930s (see discussions by McKenna, 1965; Skinner and others, 1977; Hunt, 1981). Based on lithologic and mineralogic similarities and E-log characteristics (Fig. 7), we break the Arikaree Group into three units (Fig. 4): 1) the Gering Formation; 2) Monroe Creek-Harrison formations; and 3) the Upper Harrison beds. In the northeast, the Arikaree Group is generally finer grained and browner (Table 1), making it so lithologically similar to the White River Group that differentiation is difficult.

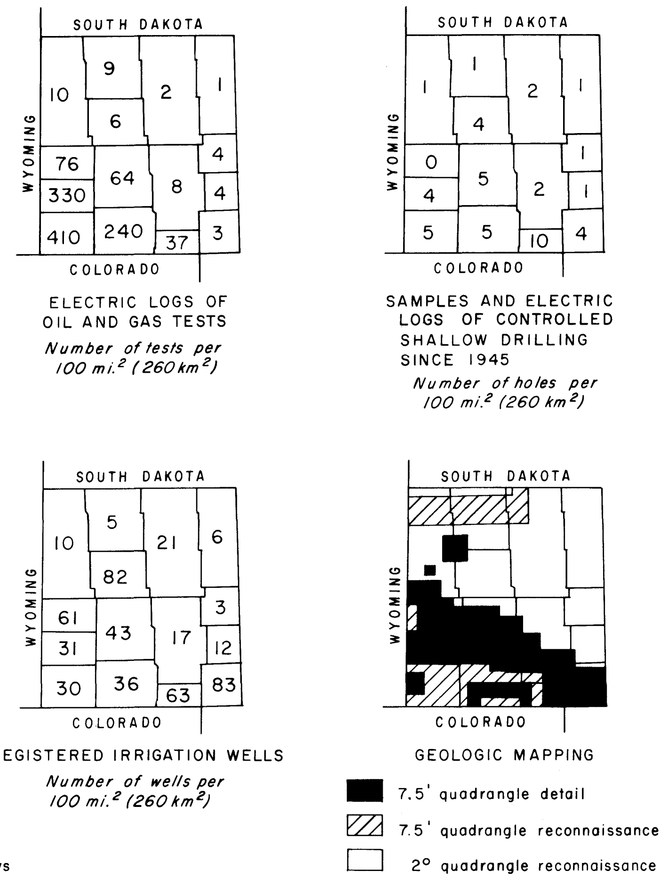


Figure 3. Index maps showing the density of the three categories of subsurface information and the distribution and level of geologic mapping.

Ogallala Group

Considerable controversy also has surrounded the stratigraphy of the Ogallala Group (e.g., McKenna, 1965; Galusha, 1975). Our usage expands the Ogallala Group to include the Runningwater through Ash Hollow formations (Fig. 4 and Table 1). The lithologic and geometric complexities characteristic of the Ogallala make correlations within and between formations difficult even in small areas of good exposures (Skinner and others, 1977; Diffendal, 1982). In the subsurface these difficulties are compounded and, with little or no accompanying surface control, recognition beyond the group level is not always possible on the basis of reconnaissance drilling (Fig. 5, C-C' and E-E').

PALEOGEOGRAPHY

Pre-Chadron

Paleocene and Eocene rocks, if deposited, were eroded before deposition of the Chadron Formation. Evidence of intense weathering (Interior Paleosol) during the Paleocene and/or Eocene is common in the study area (Schultz and Stout, 1955; Pettyjohn, 1966). This paleosol series may also have continued to form during initial deposition of the Chadron Formation (Retallack, 1983). A variety of landforms was produced by pre-Chadron erosion but they are difficult to interpret from the map of the base of the Cenozoic (Fig. 8) because of later structure. The general pre-Chadron landscape appears to have been an east-northeastward sloping plain with moderate local relief. The more resistant Upper Cretaceous Fox Hills Sandstone, Lance Formation, and Transition zone of the Pierre Shale (Fig. 9) were eroded to a more dissected topography in the southwestern part of the study area (DeGraw, 1969). Uplift along the Chadron Arch from Late Cretaceous into Early Cenozoic time caused the erosion of as much as 1800 ft (549 m) of Late Cretaceous rocks from the arch. Sparse data allow only a very generalized reconstruction of paleotopographic features along the arch.

Chadron Formation-Lower Part of Orella Member of the Brule Formation

Significant erosion, completely removing the Interior Paleosol from some lowland areas, established a drainage system prior to deposition of Chadron-lower part of Orella (Early Oligocene) sediments. The initial phase of deposition was dominated by alluvial processes as the valleys were filled. Basal sands with some gravels overlain by bentonitic clays (mostly altered pyroclastic material) typify deposits of the valleys. Clays and interbedded sands fill paleotopographic lows if coarse clastics are absent. Similar clay beds, generally thinner and probably representing paleosols (Retallack, 1983), occur on the uplands. Figure 10 is a reconstruction of the Early Oligocene paleogeography at the end of this fluvial phase (Chadron Formation, Fig. 6). The major drainage feature was a west-east through-flowing valley about 25 mi (40 km) wide entering present day Nebraska in northwest Sioux County and turning southeast in western Dawes County. Net sandstone thicknesses exceed 200 ft (61 m) in northeast Sioux County and may represent deposition in locally subsiding basins or in inner channels (Schumm, 1977). A major tributary paleovalley cuts across the southwest part of the study area parallel to the subcrop contact between the Transition zone of the Pierre Shale and the Pierre Shale (Fig. 9). This paleovalley has sand-filled tributaries originating in uplands developed on the Upper Cretaceous Fox Hills Sandstone and Lance Formation. The major paleovalley diverges east of Cheyenne County (Fig. 9). A tributary drainage system also trends from eastern Dawes into Sheridan County but it cannot be extended southeastward because of lack of control.

Filling of paleovalleys was followed by deposition of pyroclastic air-fall debris, including discrete ash beds (M ash, Fig. 6), over most of western

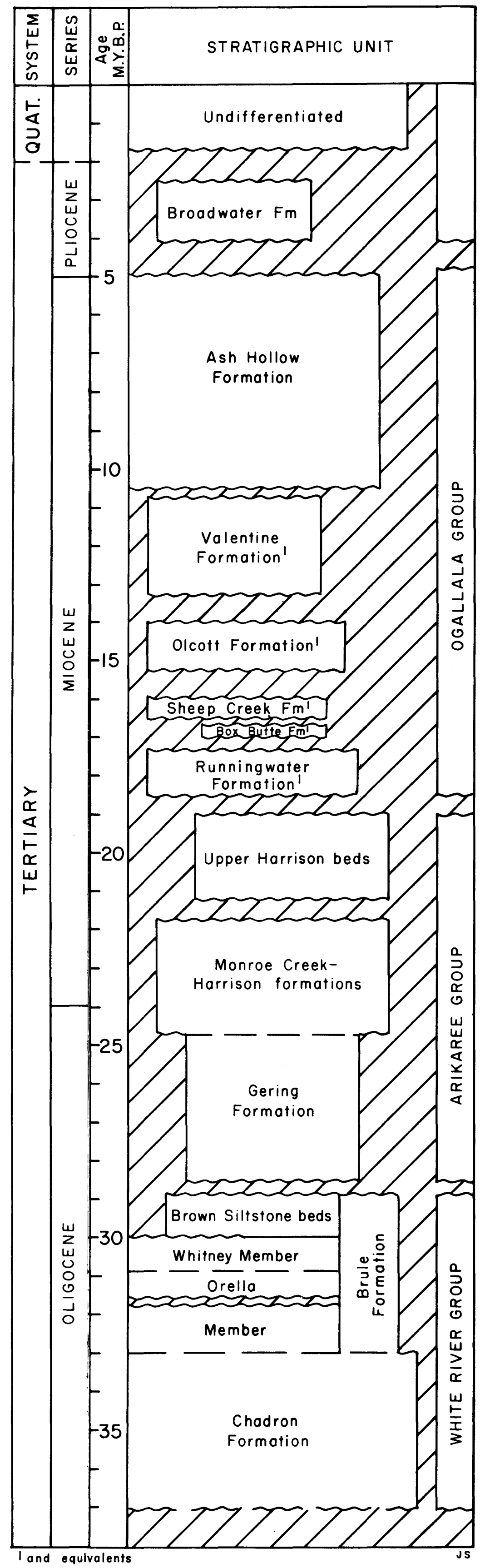


Figure 4. Time stratigraphic chart of Cenozoic units in western Nebraska. Units positioned on bases of superposition, fossil mammals and available age dates. Width of unit box indicates approximate extent of unit from south to north across study area. Slanted lines indicate a hiatus.

Table 1. Dominant lithologic characteristics of Cenozoic stratigraphic units in the study area

Group	Formation	Stratigraphic Unit	Lithologic Characteristics	Maximum Thickness
		Quaternary deposits	Sands and gravels along the North and South Platte rivers and beneath adjoining terraces; sands, silts, and minor amounts of gravel from local sources along other streams; sand dunes; and loess.	Extremely variable
		Broadwater Formation	Sands, gravels, and some silt and diatomite lenses along north side of North Platte River valley from Wyoming border to Garden County, more silts eastward.	300 ft (91 m)
Ogallala Group		Ash Hollow Formation	North part--gray, olive, and olive-brown fine- to coarse-grained sandstones, some sandy western-source gravels (abundant igneous and metamorphic clasts derived from western plutonic areas), and locally occurring ash beds. South part--gray, brown, and reddish-brown fine- to coarse-grained sandstones, silty sandstones, sandy western-source gravels, siltstones, and locally occurring ash beds. More poorly sorted and more carbonate cement than in north part. Deposits from two parts mingle in Garden and Arthur counties.	600 ft (183 m)
Ogallala Group		Valentine Formation	Gray and olive medium- to fine-grained sands and some sandy silts in the northeast. Rocks of equivalent age in the south are brown and gray poorly sorted silty sandstones, sandy silts, and locally occurring gravels mostly derived from local sedimentary sources.	200 ft (61 m)
Ogallala Group		Sheep Creek-Olcott formations	Gray, fine- to medium-grained sandstones, poorly sorted silty fine- to coarse-grained sandstones, sandy siltstones, and locally occurring volcanic ash beds. Carbonate cement common.	250 ft (76 m)
Ogallala Group		Box Butte Formation	Gray, greenish-gray, and brown clayey (montmorillonitic) silts containing large calcareous nodules that is a good stratigraphic marker in northern Box Butte and southern Dawes counties; overlie locally occurring brown to gray, poorly-sorted silty sandstones and sandy siltstones.	160 ft (49 m)
Ogallala Group		Runningwater Formation	Gray, greenish-gray, and brown medium- to fine-grained sandstones, coarse sands, sandy siltstones, western-source gravels, and locally occurring clayey silts and ash beds. Some fine-grained volcaniclastics in west.	350 ft (107 m)
Arikaree Group		Upper Harrison beds	Brown volcaniclastic sandy siltstones. Grayish-brown to gray silty fine-grained sandstones and locally occurring coarser-grained sandstones at the base. Silica-cemented horizons common in west. Generally grades from grayish-brown silty sandstones in west to brown siltstone in northeast.	300 ft (91 m)
Arikaree Group		Monroe Creek-Harrison formations	Gray, brownish-gray, and grayish brown volcaniclastic silty very fine-grained sandstones. Generally finer-grained (sandy siltstones) and browner northeastward. Carbonate-cemented horizons ("pipy concretions") common.	420 ft (128 m)
Arikaree Group		Gering Formation	Gray, brownish-gray, and grayish-brown volcaniclastic fine- to medium-grained sandstones, silty sandstones, brown sandy silts, and locally occurring beds of ash, coarse sand, and fine gravel. Generally finer-grained and browner northeastward.	350 ft (107 m)
White River Group	Brule Formation	Brown Siltstone beds	Brown volcaniclastic sandy siltstones and silty very fine grained sandstones. Mudstones and fine- to medium-grained sandstones occur locally and generally at or near base. Regionally correlative zone of ash beds (Nonpareil ash zone, new informal name) occurs in lower part.	450 ft (137 m)
White River Group	Brule Formation	Whitney Member	Brown volcaniclastic siltstones. Mudstones and fine-to medium-grained sandstones occur locally. Contains two regionally correlative ash beds (Upper Ash and Lower Ash) and several less continuous ash beds.	300 ft (91 m)
White River Group	Brule Formation	Orella Member	Brown to greenish-gray volcaniclastic mudstones and siltstones. Fine- to medium-grained sandstones and thinly bedded mudstones occur in upper part throughout broad areas. Regionally correlative ash bed (M ash, new informal name) occurs in lower part.	400 ft (122 m)
White River Group		Chadron Formation	Gray and greenish-gray bentonitic claystones and mudstones. Throughout much of the area fine- to coarse-grained sandstones and locally occurring conglomerates underlie the claystones-mudstones.	300 ft (91 m)

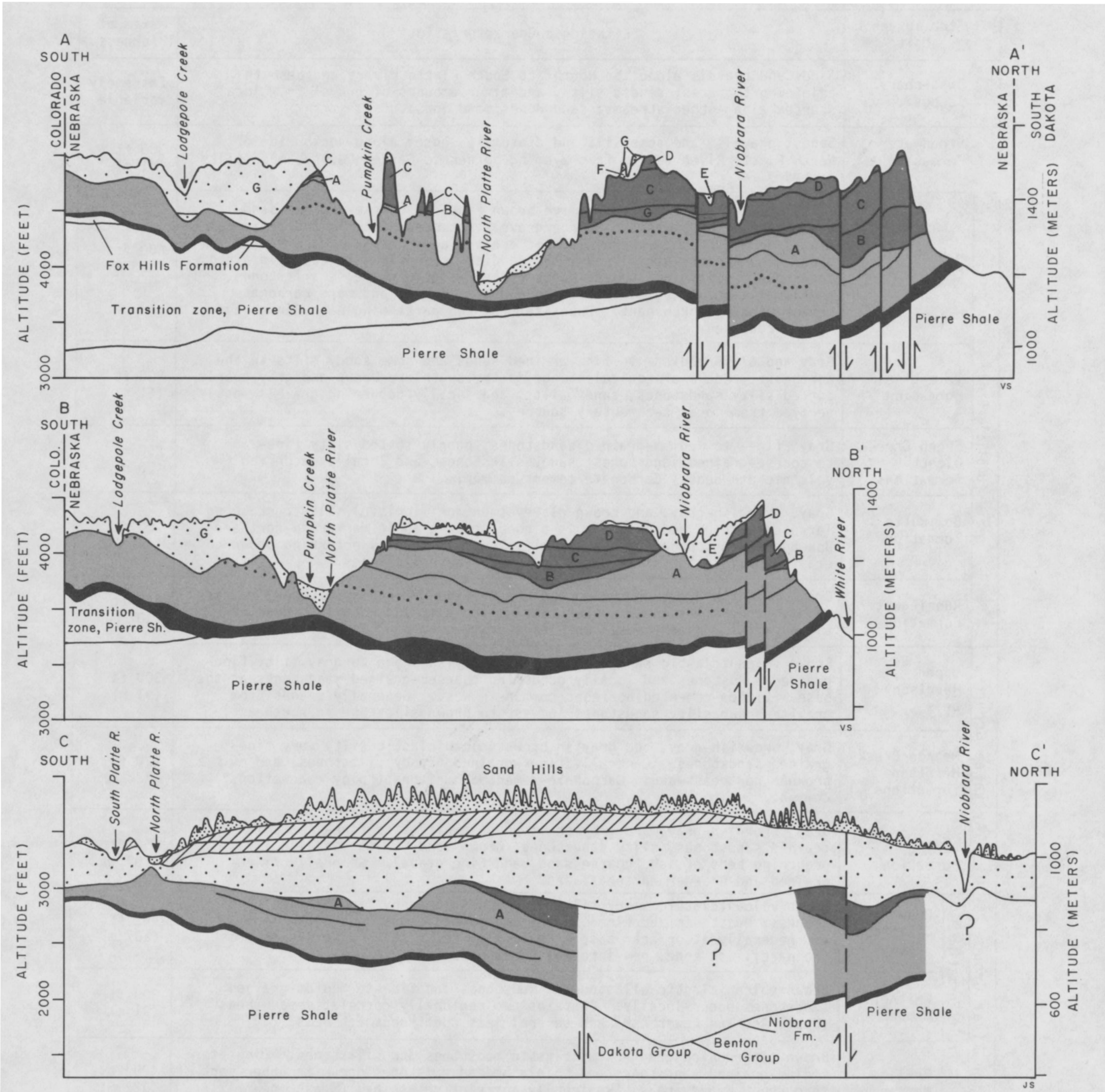
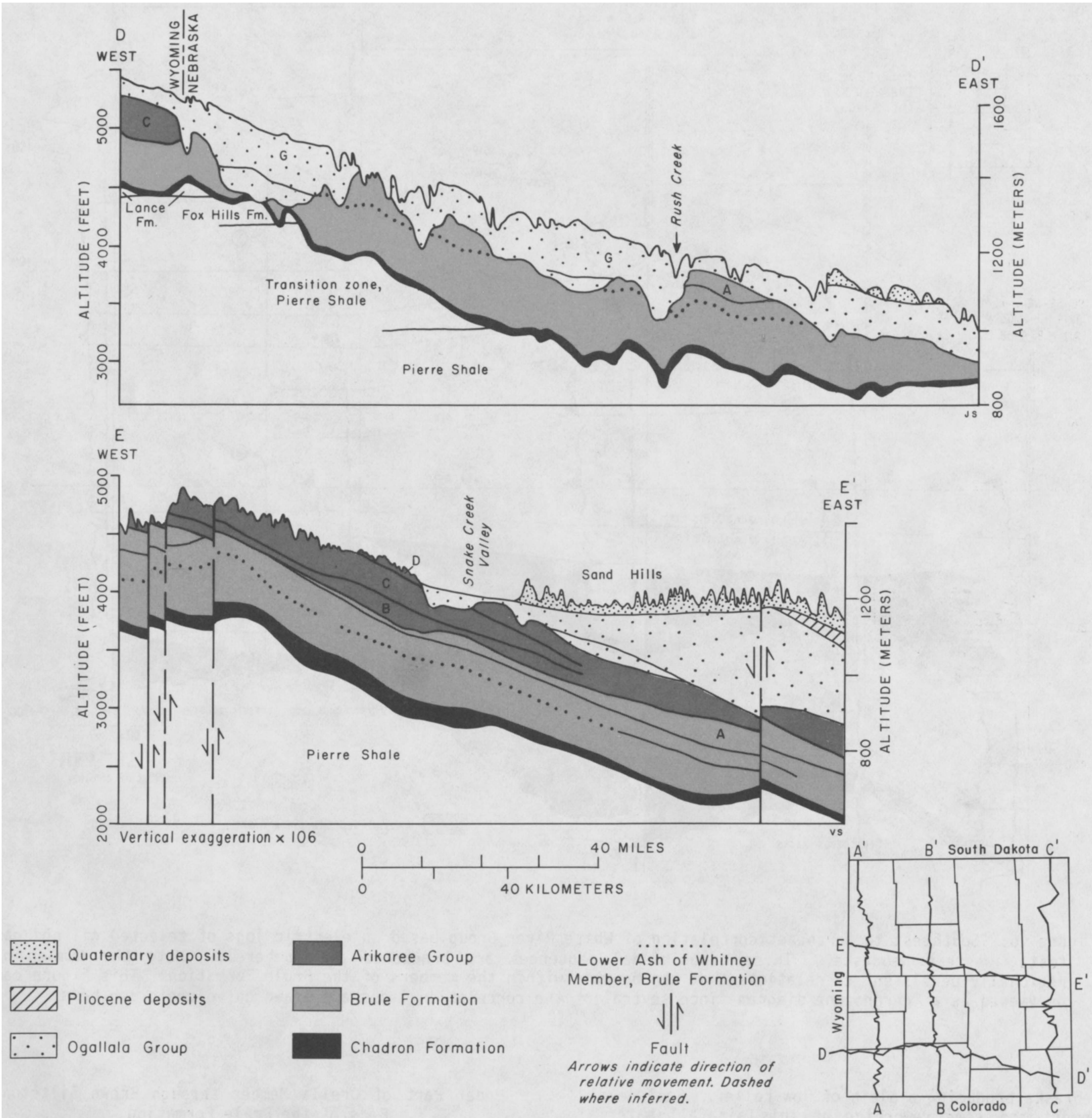


Figure 5. Geologic sections across study area. Brule Formation, Arikaree Group and Ogallala Group are subdivided in selected areas as follows: A-Brown Siltstone beds; B-Gering Formation; C-Monroe



Creek-Harrison formations; D-Upper Harrison beds; E-Runningwater Formation; F-Sheep Creek and Olcott formations; G-Ash Hollow Formation.

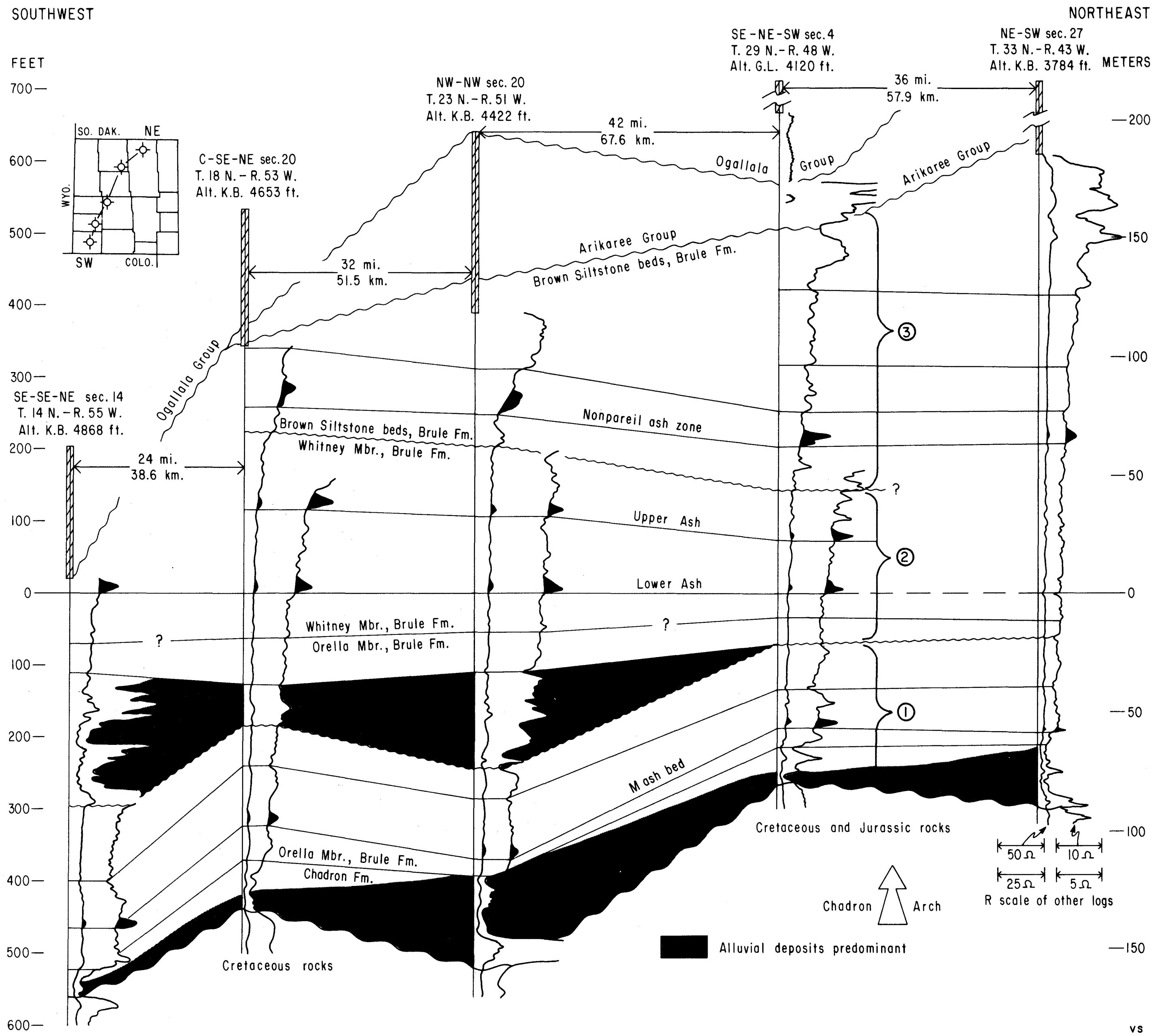


Figure 6. Southwest to northeast correlation of White River Group based on electric logs of selected oil and gas tests, western Nebraska. Three depositional sequences are bracketed and numbered. Note the number of regionally persistent correlations that can be made within the members of the Brule Formation. This figure can be viewed as a chronozone diagram since several of the correlation lines are drawn on volcanic ash beds.

Nebraska producing a plain of low relief. Soil development and some reworking of this air-fall material must have occurred, but no significant amount of coarser epiclastic detritus has been observed in the interval between the M ash and the Orella intraformational unconformity.

Upper Part of Orella Member through Brown Siltstone Beds of the Brule Formation

Initiation of regional downcutting prior to deposition of the upper part of the Orella through Brown Siltstone interval (Middle Oligocene) created a series of valleys (Fig. 6) which had less relief and were smaller than those of the Chadron Formation. Only

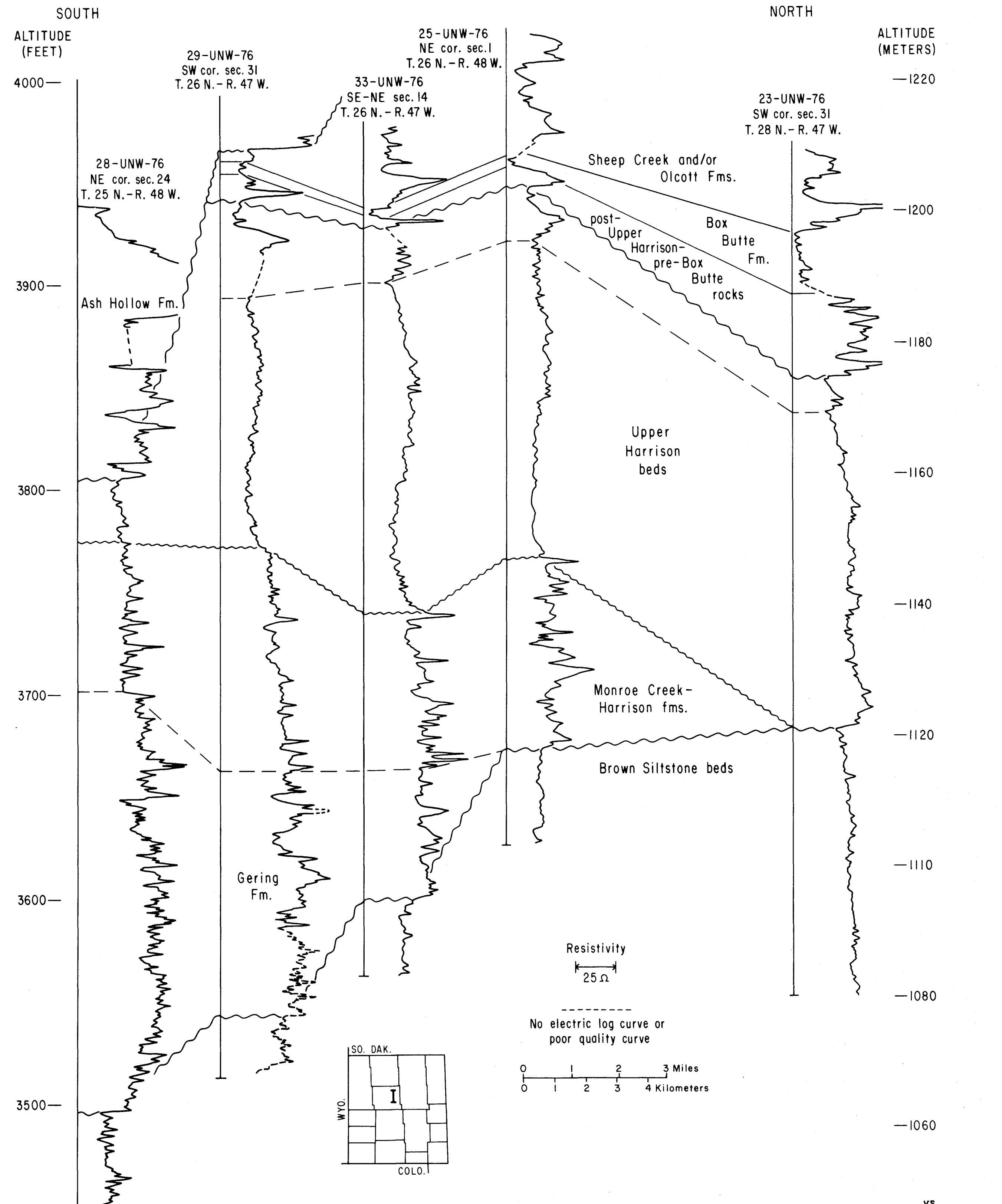


Figure 7. Correlation of Arikaree Group strata showing the profile of an upland-valley sequence in Box Butte County. Electric logs and samples from Conservation and Survey Division test holes.

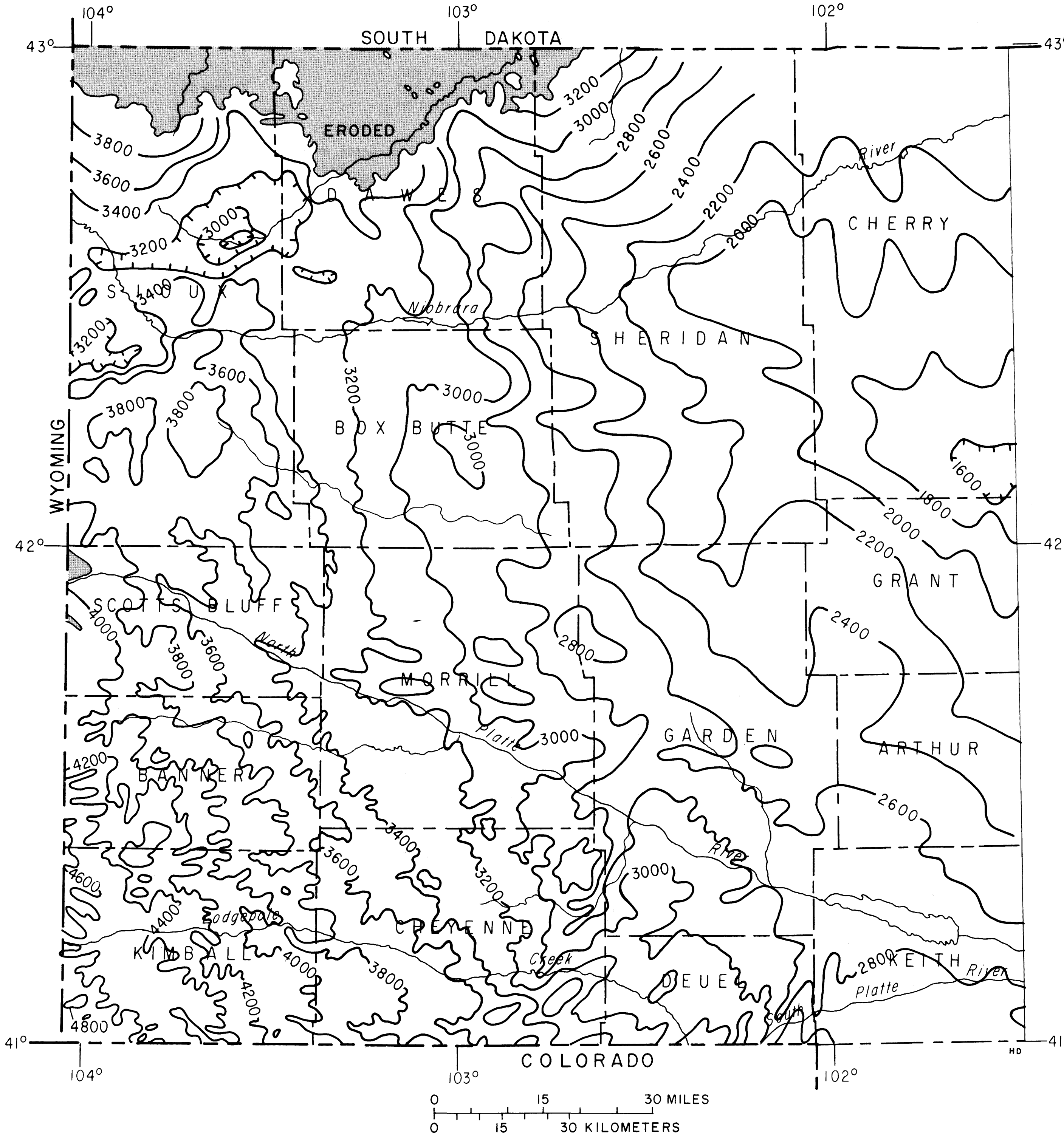


Figure 8. Configuration of the base of Cenozoic rocks in western Nebraska. Contour interval is 200 ft (61 m). This surface primarily represents the Late Cretaceous to Early Oligocene unconformity.

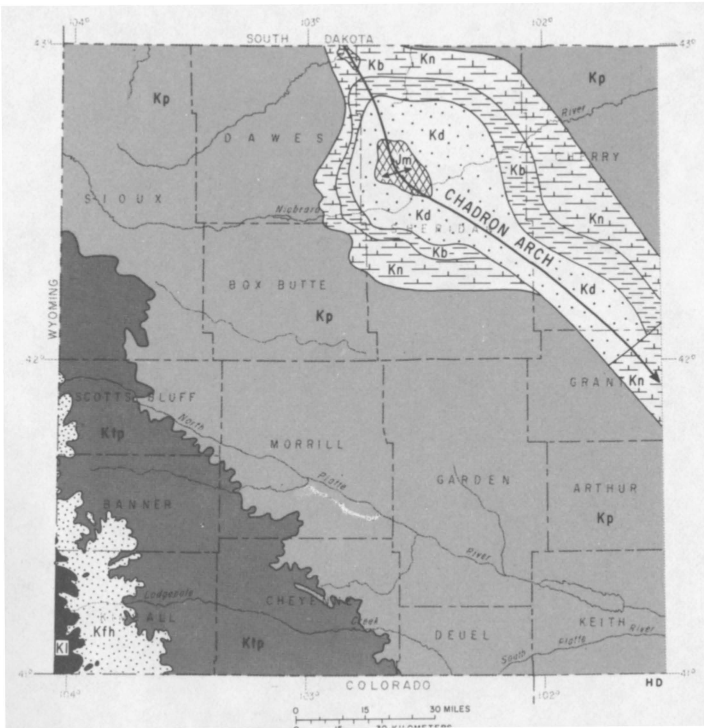


Figure 9. Pre-Cenozoic geologic map of western Nebraska. Jurassic System: Jm-Morrison Formation; Cretaceous System: Kd-Dakota Group; Kb-Benton Group; Kn-Niobrara Formation; Kp-Pierre Shale; Ktp-Transition zone, Pierre Shale; Kfh-Fox Hills Sandstone; Kl-Lance Formation.

Figure 10. Paleogeography at the close of Chadron Formation deposition (Early Oligocene), western Nebraska. Unshaded areas were predominantly well-drained rolling uplands with some local ponds. Shaded areas represent poorly drained areas of paleovalleys dominated by swamp, lacustrine, and flood plain environments. Stippled areas were primary sites of fluvial sand deposition within paleovalleys. Contour interval of net sandstone thickness, 100 ft (30 m). Note the difficulty of detecting many of these paleogeographic features on Figure 8 because of post-Early Oligocene structural movements. Uranium locality from Collings and Knode (1984).

Table 2. Percentages $(\bar{X} \pm \sigma)$ of volcanic glass in the Cenozoic strata of western Nebraska

Stratigraphic Unit	Number of Samples	Percentage of Glass Shards in vf sd	Median Grain size (mm)
Ogallala Group	40	7 ± 5	0.4
Arikaree Group	222	28 ± 10	0.1
White River Group	125	53 ± 14	0.04

Most of the samples shown above are from Conservation and Survey Division test holes. The remainder are outcrop samples. Each sample was sieved, treated with 10 percent HCl and 3 percent HF to remove carbonate and diagenetic clay, a grain mount made of the very fine sand (vf sd) fraction and 300 grains were counted. The median grain size is an estimate based on selected sieve data.

minor amounts of sand and coarser clastics were deposited in the valleys and much of this sediment appears to have been reworked from older fine-grained rocks of the White River Group. The coarser clastics were derived from metamorphic and igneous rocks in southeastern Wyoming (Stanley, 1976). Eolian volcaniclastic silt and thin lenses of pure volcanic ash also occur in these valley-fill deposits. Minor pyroclastic air-fall deposition and soil-forming processes (Schultz and others, 1955) took place on uplands. Subsurface information indicates the paleodrainages of this erosional episode trend generally west to east. This marks a departure from the more complicated pattern of the Chadron paleovalleys.

White River sedimentation subsequent to this episode of alluviation was dominated by air-fall deposition of fine-grained pyroclastic (primarily vitric) debris (Table 1) which constructed a northeastward-sloping plain of low relief. Several times during this interval discrete vitric ash beds were deposited

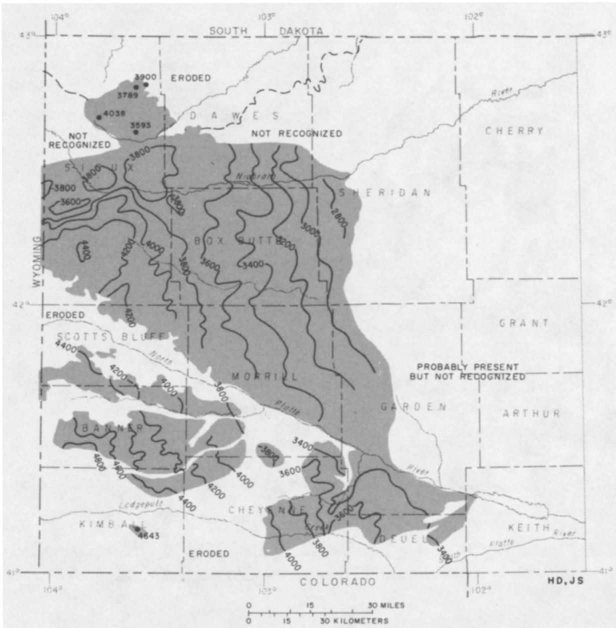


Figure 11. Occurrence of the Lower Ash of the Whitney Member in western Nebraska and configuration of its base. Contour interval is 200 ft (61 m). The Lower Ash contains 85 to 95 percent rhyolitic glass shards and is biotitic. Thickness typically ranges from 5 ft (1.5 m) to 12 ft (3.6 m) and the ash thins toward the east-northeast.

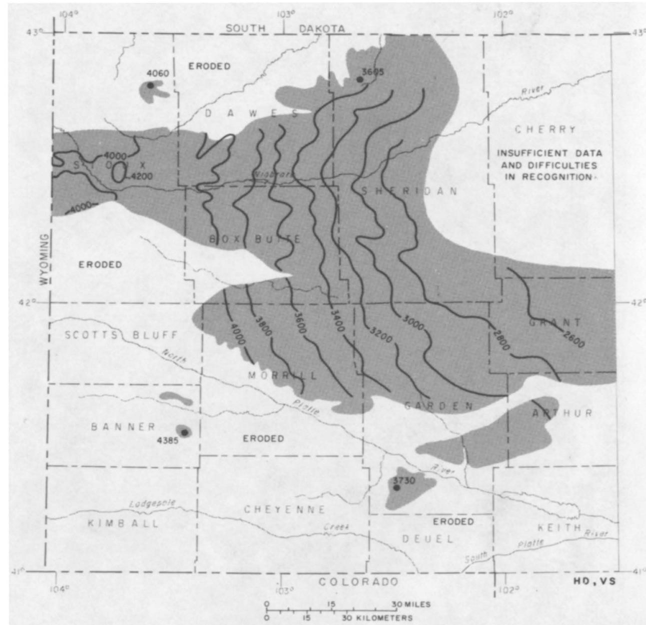


Figure 12. Occurrence of the Nonpareil ash zone, Brown Siltstone beds, in western Nebraska and configuration of its base. Contour interval is 200 ft (61 m). Thickness typically ranges from 30 ft (9.1 m) to 50 ft (15 m) and the zone may contain up to 3 discrete biotitic, vitric ash beds. Maximum observed thickness of a single ash bed is 20 ft (6.1 m) in southern Dawes County.

across much of western Nebraska (Fig. 6). The distribution and configuration of the Lower Ash of the Whitney Member (Fig. 11) and the Nonpareil ash zone (a new informal name; Fig. 12), although modified by subsequent structural movements, document the absence of significant relief. Braided and ephemeral streams did cross this plain, however, and deposited sediments dominated by epiclastic material (Stanley, 1976). Although volumetrically small in relation to the eolian deposits, this alluvial facies has been encountered locally throughout the entire interval of the White River Group. Valleys were probably cut less than 50 ft (15 m) deep and were narrow. A paleovalley in the Brown Siltstone beds contains up to 200 ft (61 m) of fill and crosses north-central Sioux County from west to east paralleling the Pine Ridge in Dawes County.

The White River sediments and landscapes are overwhelmingly products of the deposition of fine-grained pyroclastic material. This material, typified by glass shards (Table 2), was derived from western-source rhyolitic and andesitic volcanic centers (Fig. 13). The distribution and northeast slope of the ashes (Figs. 11 and 12) and northeast thinning of the Lower Ash and many White River Group stratigraphic units (Fig. 6) indicate that volcanic centers in Colorado were the most probable sources for ash in western Nebraska and that southwesterly winds predominated during the deposition of the White River Group.

Arikaree Group

The essentially continuous building of a succession of low-relief landscapes in western Nebraska by the aggradation of pyroclastic eolian material was interrupted in the Late Oligocene when the region was subjected to widespread fluvial erosion. This erosion produced the unconformity which separates the Gering Formation (Arikaree Group) from older Cenozoic units (Figs. 4 and 7). Two major drainage systems and at least one smaller one were developed (Fig. 14). Maximum depths of cutting ranged from about 300 ft (91 m) in the north to about 100 ft (30 m) in the south (Fig. 5). The general west-east trend of these drainages represents a significant shift from the southeasterly trend of the major Early Oligocene paleovalley (Fig. 10). Sediments within the Gering paleovalleys reflect multiple cuts and fills and include some eolian deposits. Tracing the small southern paleovalley is facilitated by the unique occurrence of pumice pebbles in one of the fills. The pumice was transported by a Gering river with headwaters in a volcanic field in north-central Colorado (Izett, 1975; Fig. 13).

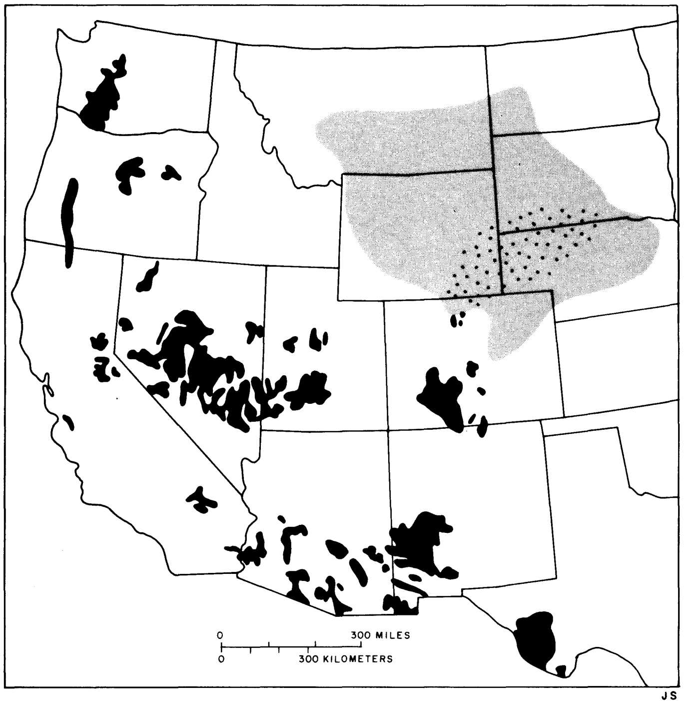


Figure 13. Generalized distribution of rhyolitic and andesitic rocks between 35 and 18 m.y. old (black) in the western United States (after Stewart and Carlson, 1978) and the minimum probable extent of the White River (shaded; after Robinson, 1972) and the Arikaree Group (stippled).

Direct air-fall and wind blown pyroclastic detritus (Monroe Creek-Harrison formations) succeeded the deposition of the complex set of alluvial fills (Gering Formation) and an aggrading plain of low relief again dominated the western Nebraska landscape. The southern part of the area may not have received any sediment accumulation during this time (Fig. 13). Minor amounts of volcaniclastic alluvial deposits occur at a number of horizons within the Monroe Creek-Harrison unit and indicate that small local drainages were present. Vicars and Breyer (1981) noted such a deposit associated with eolian dunes in central Sioux County.

A second period of regional erosion, typified by valleys of low relief and low-angle side slopes, resulted in an unconformity that separates Monroe Creek-Harrison sediments from the Upper Harrison beds (Fig. 4). This erosion, while not producing as much down cutting as pre-Gering erosion, was sufficient to remove thin accumulations of Monroe Creek-Harrison deposits from divides between Gering paleovalleys in several areas so that Upper Harrison beds rest directly upon rocks of the White River Group (Fig. 7). Hunt (1981) and Vicars and Breyer (1981) described one of these basal Upper Harrison valley fills in central Sioux County that contains a maximum of about 40 ft (12 m) of fine sandy volcaniclastic alluvial deposits. Our studies indicate that a coeval valley fill with up to 60 ft (18 m) of somewhat coarser material occurs in northern Sheridan County.

Following the filling of these valleys, the accumulation of pyroclastic material once again resumed and eolian deposits of the Upper Harrison blanketed much of western Nebraska. As in preceding intervals dominated by eolian processes, deposition greatly exceeded erosion. The principal differences between the pyroclastic materials in the Arikaree Group and those of the White River Group are the larger grain size and smaller percentage of glass shards in the Arikaree (Table 2). However, the total pyroclastic contribution to the eolian deposits of the Arikaree Group exceeds 75 percent (Vicars and Breyer, 1981; Hunt, 1981). The textural and mineralogic changes may reflect a shift in volcanic source areas (Fig. 13), a change in high-altitude wind patterns (Stanley, 1976), or eolian reworking of older pyroclastic deposits in present day northern Colorado. No widespread ash marker beds have been identified in the Arikaree Group, although a number of ashes are known to occur, especially within the Gering Formation.

Ogallala Group

Landscape development in western Nebraska underwent a major change in the Middle Miocene beginning with the period of erosion separating the Arikaree and Ogallala groups (Figs. 4 and 15). Widespread eolian

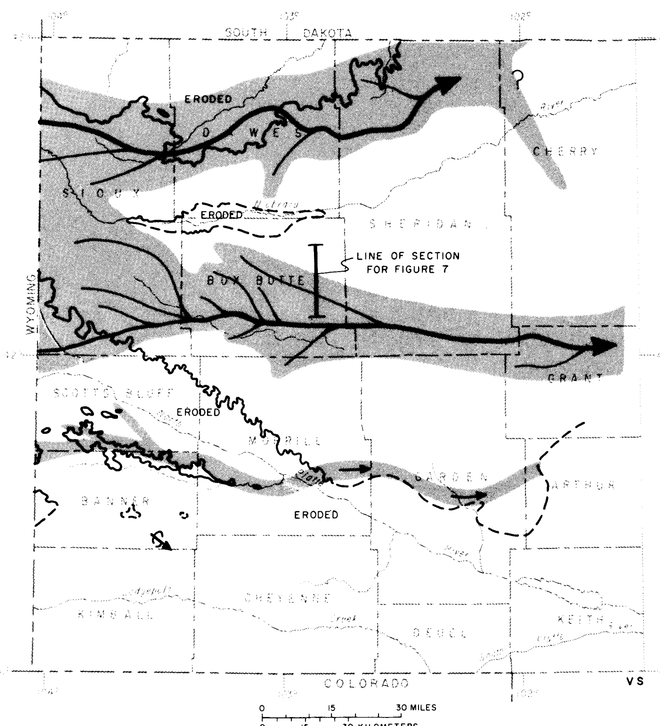


Figure 14. Inferred paleodrainage systems (arrows) of the Gering Formation, Arikaree Group, western Nebraska. Known and inferred extent of the formation is shaded. In drainage divide areas (e.g. central Sioux County), some thin Monroe Creek-Harrison alluvial deposits may be included in the Gering. Present distribution of Arikaree Group shown by even-weight line, dashed where inferred.

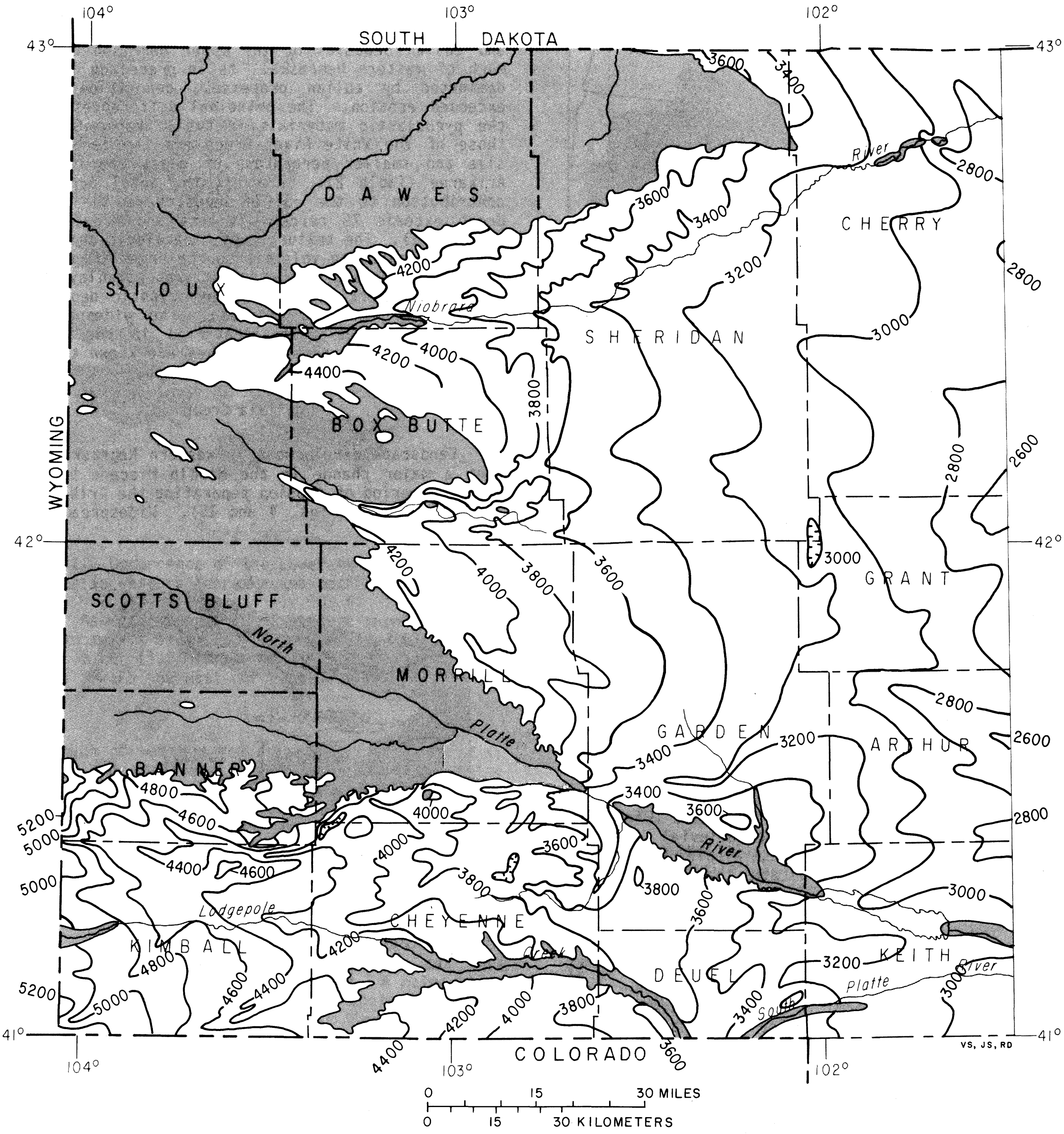


Figure 15. Configuration of the base of the Ogallala Group, western Nebraska. Contour interval is 200 ft (61 m). Shaded where Ogallala eroded.

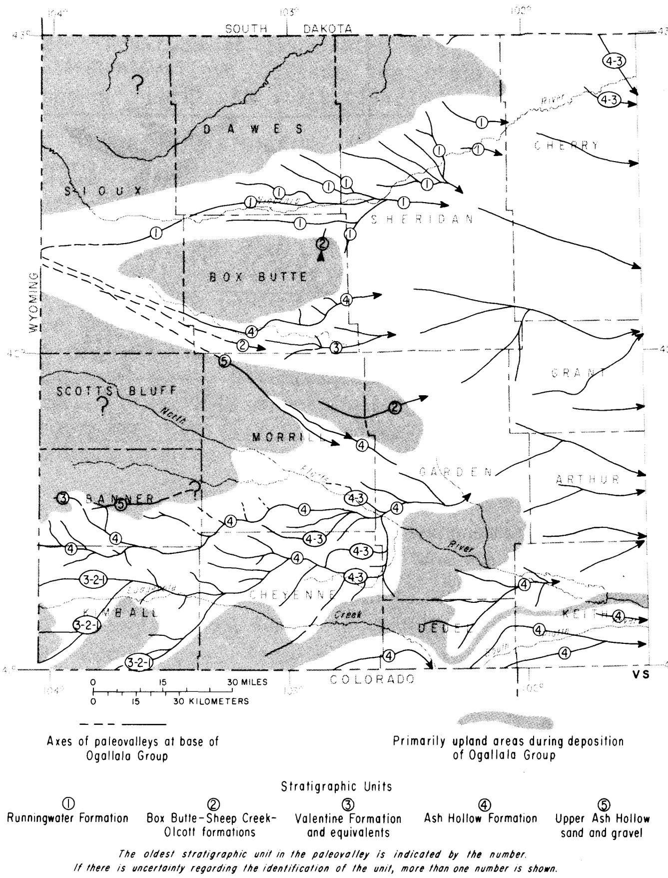


Figure 16. Postulated distribution of Ogallala paleovalleys.

deposition gave way to restricted alluvial deposition in valleys. During the last two thirds of the Miocene a wide variety of drainage systems of different sizes, the larger heading in the mountains of Wyoming and Colorado, were developed and subsequently filled with epiclastic material. The base of the Ogallala Group (Fig. 15) rests on a composite surface eroded at different times and places. Figure 16 illustrates in a general way the time transgressive nature of this surface.

The largest of the older Ogallala paleovalleys is located in the northern half of the study area and is filled with alluvial sediments of the Runningwater Formation. The paleovalley is about 15 mi (24 km) wide in Dawes and Box Butte counties where maximum cutting was about 300 ft (98 m) (Fig. 5, B-B'). Yatkola (1978) and Souders and others (1980) described the complex cuts and fills of the Runningwater Formation within this paleovalley in eastern Sioux, southern Dawes and northern Box Butte counties. Sediments that may be age equivalents of the Runningwater through Valentine formations occupy parts of a smaller paleovalley system in Kimball and Cheyenne counties. This age assignment is made on the basis of stratigraphic position and lithologic similarities between these fills and valley fills containing dated vertebrate fossils in northeast Colorado just south of Kimball County (Galbreath, 1953) and in southeast Wyoming 30 mi (48 km) west of Kimball County (Cassiliano, 1980). The erosional remnants of a complex set of Sheep Creek and Olcott paleovalley fills in south-central Sioux County (Figs. 16 and 5, A-A') were mapped by Skinner and others (1977). Galusha (1975) described the narrow fills of the Box Butte Formation in Dawes and Box Butte counties.

Immediately preceding Ash Hollow deposition, several valleys were developed in present day southern Box Butte County and the southwest part of the study area (Fig. 16). Subsequent fills, like those of the older Ogallala Group, consist of a number of separate cut and fill sequences exhibiting frequent lateral facies changes over short distances. These fills, particularly those containing coarse sediments, can be separated from one another at outcrop sites and the age relationships determined (Fig. 17; Diffendal, 1982). However, the paleovalleys are often so narrow, less than 1 mi (1.6 km) wide, and have such sinuous, irregular geometries, that their discrimination and correlation in the subsurface is difficult without close spaced drilling.

In marked contrast to the White River and Arikaree groups, the Ogallala Group contains much less admixed pyroclastic debris (Table 2; Stanley, 1976). The group does have a significant number of rhyolitic ashes (Figs. 17 and 18; Skinner and others, 1977; Diffendal, 1982). The areal extent of these ashes is much less than those of the White River Group (Figs. 11 and 12). No single Ogallala ash is known to extend over an area larger than 5 mi^2 (13 km^2) and none has so far proved useful for regional subsurface correlation. Potential source areas for Ogallala ashes younger than 17 m.y. are different from those which yielded White River and Arikaree pyroclastic material (compare Figs. 19 and 13). This 17 m.y. date was used as a geologically important division point for Cenozoic igneous rocks in the western United States by Stewart and Carlson (1978) because it is approximately the low point of a significant lull in igneous activity and marks a change from eruptions of predominantly calc-alkalic rhyolites and andesites to bimodal assemblages of basalt and rhyolite.

We have not attempted to correlate the paleovalley systems and fills in the eastern part of the study area (Figs. 5 and 16) because of the absence of exposures and sparse subsurface data. This region, now overlain mostly by sand dunes, was a major area of Ogallala deposition.

Broadwater Formation and Quaternary Deposits

During the last 5 m.y., erosion greatly exceeded deposition in western Nebraska and there is little sedimentary record available over most of the area. The modern North Platte River from the Wyoming-Nebraska state line to Garden County follows a trend that was established near the end of the Miocene by a valley in the uppermost part of the Ash Hollow (Figs. 16 and 20). During the Pliocene and Quaternary a succession of valleys maintained this trend but shifted progressively to the southwest (Fig. 20). Remnants of

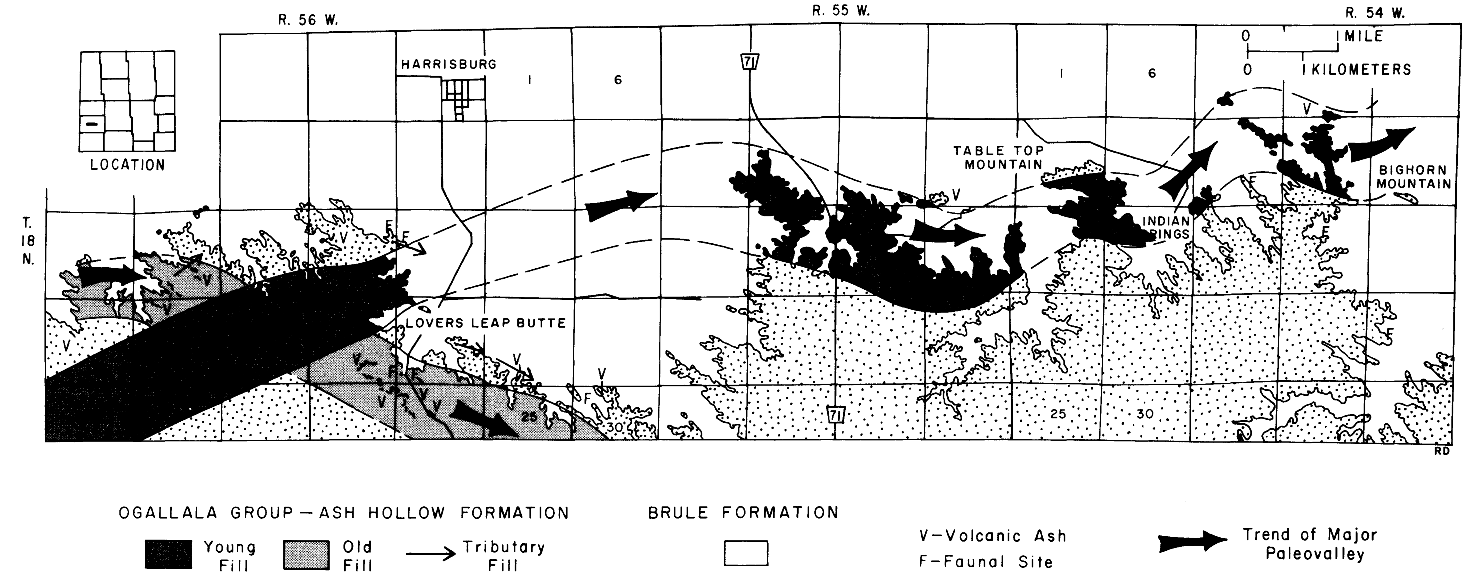


Figure 17. Distribution and age relations of Ash Hollow Formation paleovalleys in Banner County. Undifferentiated Ash Hollow of wide age range indicated by stipple pattern but not shown where it covers old fill.

coarse-grained inner channel fills, similar to those described by Schumm (1977), occur at the base of the (Pliocene) Broadwater Formation (Swinehart, 1981) and define a paleovalley axis. In eastern Morrill and Garden counties the Broadwater paleovalley trends eastward and a complex and widespread sequence of sand and gravel was deposited in the southern Sand Hills (Fig. 5, C-C') and on to the northeast.

Development of the ancestral Pumpkin Creek drainage system, heading in the southern Laramie Range, began no later than the Early Pleistocene (Corner and Diffendal, 1983) and joined the ancestral North Platte drainage in southeastern Morrill County (Fig. 20). The ancestral Pumpkin Creek was pirated by tributaries of the North Platte River immediately west of the Wyoming-Nebraska state line and in south central Morrill County in Nebraska late in the Pleistocene (Diffendal, 1984). The Lodgepole and Niobrara drainage systems are probably Middle to Late Pleistocene features. The present South Platte River valley (Fig. 20) has been the location of a major drainage way from the beginning of the Pliocene, a situation similar to that described by Scott (1982) in northeasternmost Colorado. Ahlbrandt and others, (1983) documented episodic eolian deposition during arid intervals of the Holocene that formed the Sand Hills (Fig. 5, C-C', E-E').

SEQUENCE OF PALEODRAINAGE DEVELOPMENT

The locations of paleovalleys for five post-Eocene stratigraphic intervals and the relationship of the paleovalleys to nearby positive elements are shown in Figure 21. West to east drainage predominated except for the Chadron Formation. Major drainageways of the Gering Formation and the lower part of the Ogallala Group were located in the northern half of the study area but had shifted southward by the time sediments of the upper part of the Ogallala Group were deposited. Skinner and Johnson (1984) prepared a similar map for the stratigraphic equivalent of the upper part of the Ogallala Group. Deposits of this interval were spread more widely across the plains than those of preceding intervals and regionally the

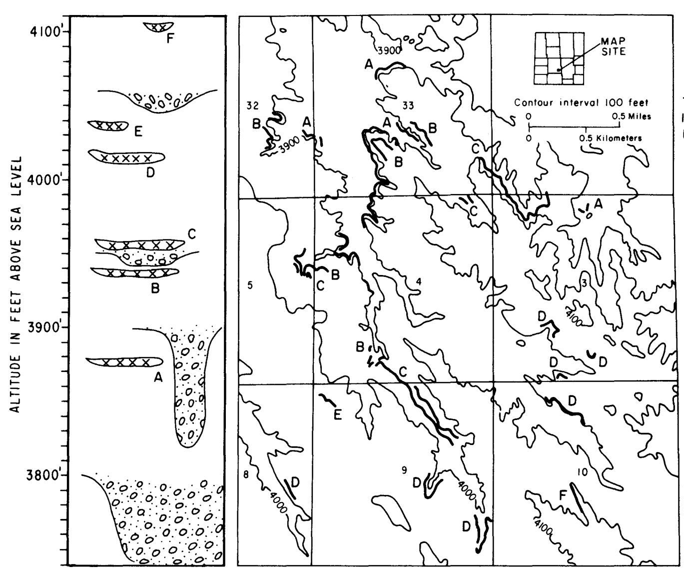


Figure 18. Map of a part of Morrill County showing six superposed and areally restricted ash lentils in the Ash Hollow Formation. Topography from USGS Fairchild Ranch 7½' quadrangle. The position of the ashes with respect to sand and gravel deposits shown at left. More ashes appear to occur where the formation is thicker and contains significant amounts of coarse-grained deposits.

Front Range became more prominent as a source of sediment. Position of Broadwater and equivalent (Pliocene) paleovalleys outside the study area are from Swinehart (1981) and Scott (1982).

CENOZOIC STRUCTURE AND PALEOGEOGRAPHY

Deposition of the Lance Formation at the conclusion of the Cretaceous probably occurred only in the southwest part of the study area (Fig. 9) at elevations slightly above sea level. The present maximum altitude of the Lance Formation is 4800 ft (1463 m) above sea level (Figs. 8 and 9) and much of this uplift probably occurred during the Paleocene (Trimble, 1980). By Early Oligocene (basal Chadron Formation) up to 1800 ft (549 m) of Mesozoic age rocks had been eroded from parts of the Chadron arch and an east-northeast sloping plain was established.

Regional uplift occurred in the south part of the study area sometime in the Oligocene prior to deposition of the Gering Formation (Figs. 5, A-A', B-B' and 8). A structural hinge in the vicinity of the present North Platte River (Fig. 22) was established and as much as 400 ft (122 m) of uppermost White River Group rocks were eroded from parts of the uplands to the southwest. Gering deposition was concentrated in the northern part of the study area and the paleodrainages have a distinctly different orientation than do Chadron paleovalleys (Fig. 21, Chadron and Gering formations). Normal faults, especially along parts of the Pine Ridge (Fig. 2), are suspected to have controlled the location of some of the Gering paleovalleys.

Further regional uplift, accompanied by local faulting and folding in the study area, post-dates deposition of the Upper Harrison beds. The White Clay Fault (Figs. 2 and 22) is post-Upper Harrison and has vertical displacements ranging from less than 300 ft (91 m) to as much as 700 ft (213 m). Ash Hollow fluvial deposits occupy the downthrown block of the fault (compare Figs. 2 and 22) and lie at the base of an escarpment capped by Upper Harrison beds. The Agate and other faults (Hunt, 1981) in Sioux County (Figs. 2 and 5, A-A') also cut Upper Harrison beds. Vertical displacement across the Agate Fault is 230 ft (70 m) in one locality. Collings and Knode (1984) report that the White River Fault (Fig. 22) has a vertical displacement that ranges from 100 to 400 ft (30 m to 122 m). The fault cuts rocks of the White River Group in western Dawes County and rocks of the White River and Arikaree groups to the west in Sioux County. These faults, and those inferred to occur along the Pine Ridge and the Niobrara River, are a continuation of the Whalen trend in Wyoming (Hunt, 1981). The principal Runningwater paleovalley appears to have developed along one faulted zone of this trend (compare Figs. 16 and 22).

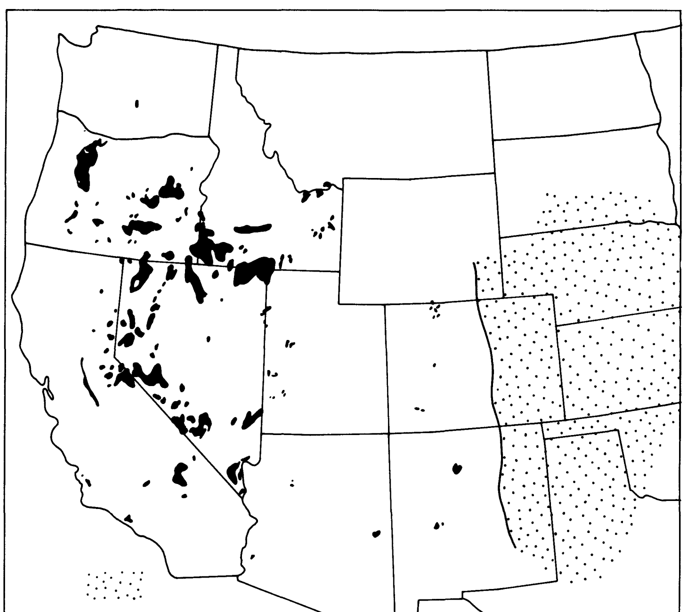


Figure 19. Generalized distribution of rhyolitic, dacitic and andesitic volcanism between 17 and 5 m.y. old (black) in the western United States (after Stewart and Carlson, 1978; Smith and Luedke, 1984) and the minimum former distribution of the Ogllala Group.

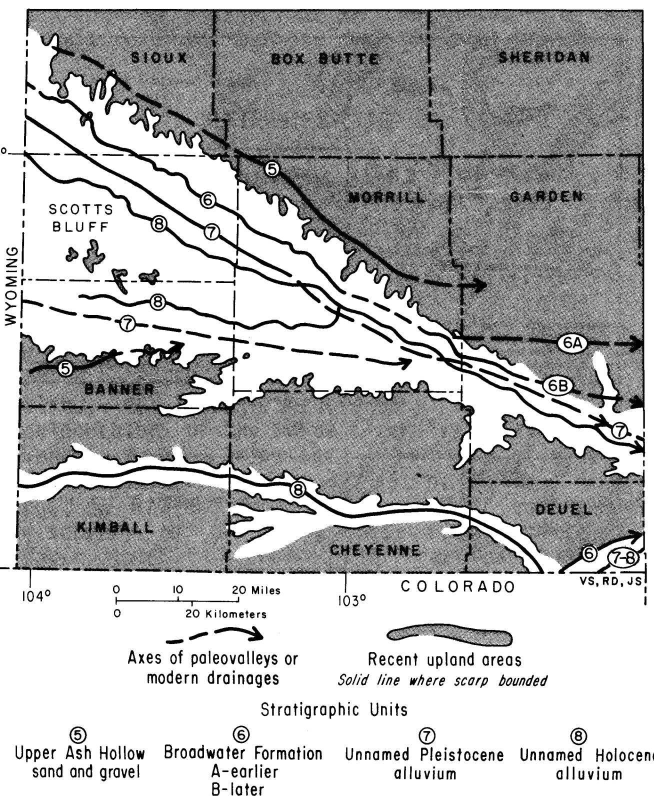
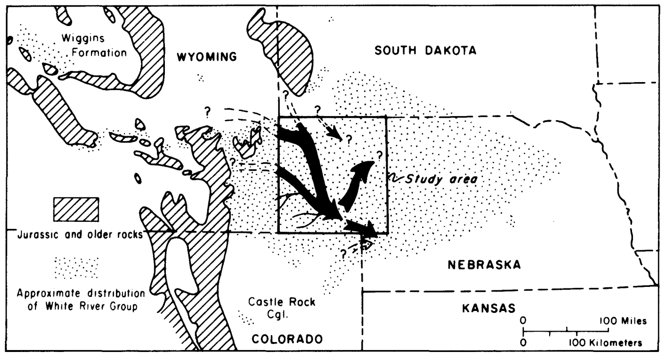
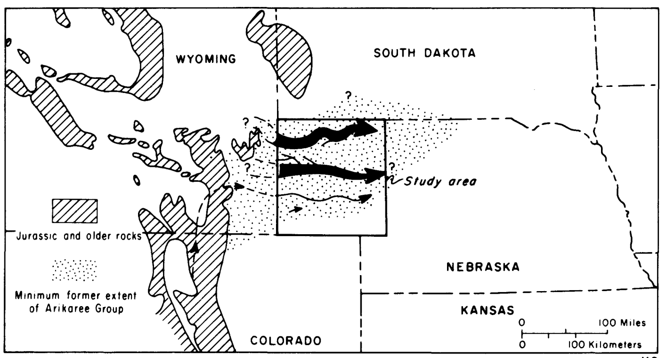


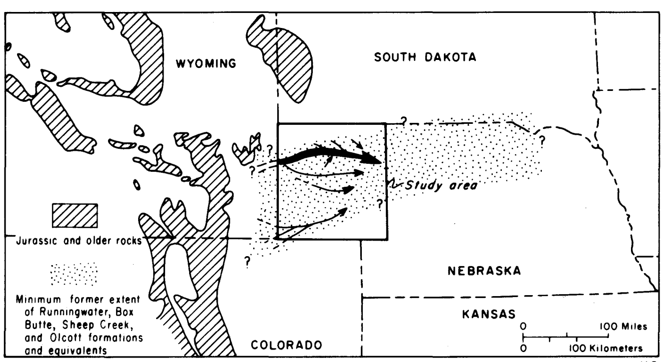
Figure 20. Axes of Upper Ash Hollow and younger paleovalleys in the southern part of western Nebraska.



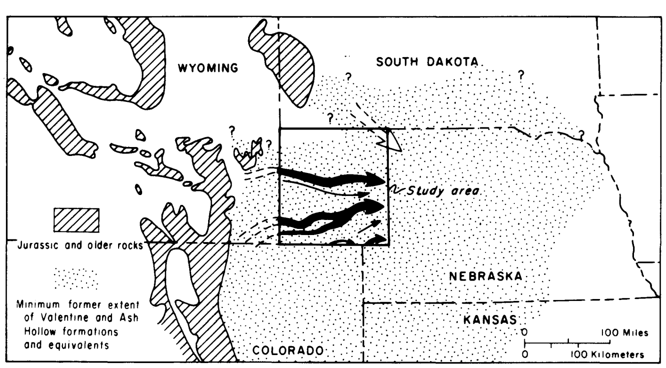
Chadron Formation



Gering Formation



Ogallala Group – lower part



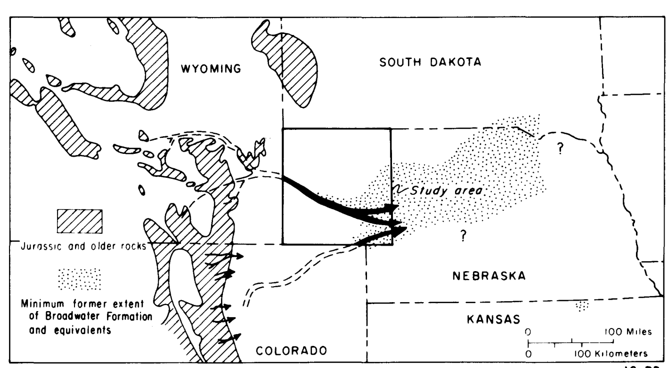
Ogallala Group – upper part

Regional uplift, probably centered in the Front Range (Fig. 1), caused deep incision of valleys prior to deposition of the Ogallala Group (Figs. 5, A-A', D-D' and 15) and completely removed the White River Group in one locality. The Rush Creek structural feature and the North Platte hinge funneled sediments of the Ogallala Group into a narrow gap in southeast Morrill County and directed them to the northeast. The Rush Creek feature remained active into the Pliocene (compare Figs. 20 and 22; Diffendal, 1980). Up to 400 ft (122 m) of Ogallala alluvial deposits occupy the subsiding part of the Big Springs feature (Fig. 5, D-D'). Pre-Ogallala Cenozoic rocks dip relatively steeply and uniformly toward the structural low at the east edge of the study area (Figs. 5, E-E', and 22) while the present land surface flattens. The low contains at least 700 ft (213 m) of post-Arikaree clastics, one of the thickest sections of these rocks in the Great Plains. The flattening indicates post-Ogallala uplift along the Chadron Arch.

Other post-Ogallala epeirogenic and local movements affected deposition of the Broadwater Formation and determined the courses of some of the younger drainages. The Broadwater drainage was diverted northeastward by the Rush Creek structure (compare Figs. 20 and 22). Later in the Pliocene the anticlinal part of this structure was breached and the ancestral North Platte River assumed its southeastward course through the eastern part of the study area. Structural movements late in the Pleistocene probably caused piracy of the ancestral Pumpkin Creek immediately west of the Wyoming-Nebraska state line.

To the north, the Niobrara River parallels the Runningwater paleovalley in southern Dawes County (Fig. 16) and then diverges to the northeast across the crest of the Chadron Arch (Fig. 22). Late Quaternary alluvial fills occur high above the river across Sheridan and Cherry counties and the Niobrara flows in entrenched meanders near the White Clay Fault (Fig. 22). These features indicate that Late Quaternary structural activity influenced the drainage and seismic activity along the arch continues today (Burchett, 1979). In Dawes County, a modern stream (the White River) parallels two faults for much of its length (Fig. 22).

Figure 21. Regional setting of Cenozoic paleodrainages.



Broadwater Formation

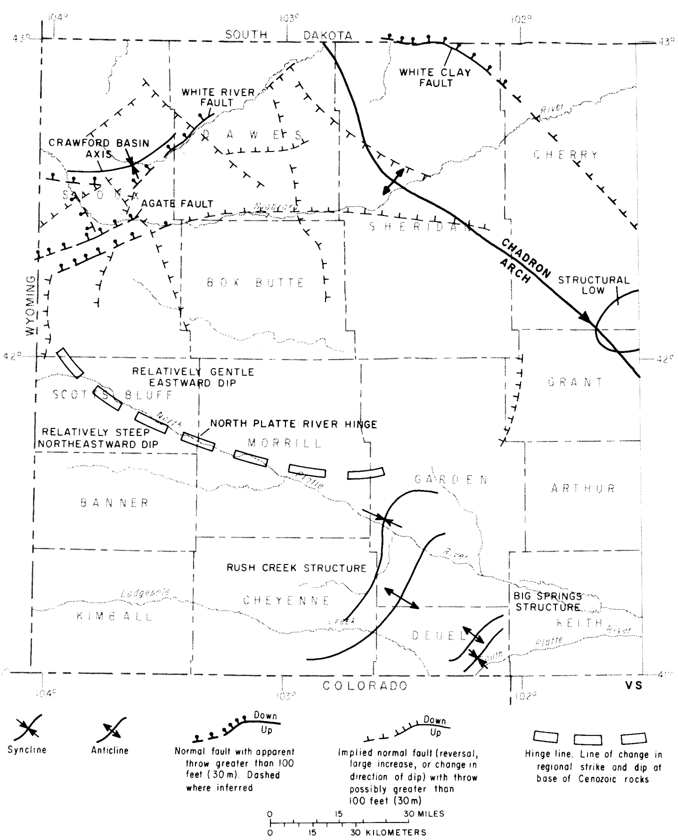


Figure 22. Significant known and suspected Cenozoic structural features of western Nebraska primarily compiled from overlays of maps of the base of the Cenozoic (Fig. 8), Ogallala Group (Fig. 15), and from the configuration of Lower Ash of the Whitney (Fig. 11).

As outlined above, local structural control of post-Ogallala drainages is apparent in parts of the study area. The magnitude of regional uplift is indicated most strongly by the large amount of erosion that has occurred in the region since deposition of the Ogallala Group. Scott (1982) noted a similar situation in northeastern Colorado. The North Platte River in central Scotts Bluff County is at least 1000 ft (305 m) lower than the Ogallala-capped tablelands on either side of the valley (Fig. 2). In the north near the Wyoming border, the Pine Ridge escarpment rises 1200 ft (366 m) above Pierre Shale hills (Fig. 5, A-A') and relief gradually decreases to about 400 ft (122 m) at the east end. All Tertiary rocks were eroded from the area north of the ridge while most of the Ogallala Group and much of the Arikaree Group were removed from the western part of the uplands between the Pine Ridge and the North Platte River valley (Fig. 2).

Cenozoic structural events and associated geographic features are certainly more complicated than discussed here. Generally speaking, episodic regional uplift and local adjustments took place throughout the Cenozoic and presumably are expressions of varying degrees of structural movements in the Rocky Mountains to the west. The approximate times and relative magnitudes of post-Laramide uplift are represented in an oversimplified, qualitative fashion by the negative slopes on the cumulative graph (Fig. 23). Trimble (1980) suggests a simpler picture of Cenozoic tectonic history of the Southern Rocky Mountains and Great Plains. Figure 23 furthermore illustrates the importance of pyroclastic air-fall material in the construction of the High Plains of westernmost Nebraska.

Climatic conditions and internal sedimentary controls (Schumm, 1977) can greatly influence erosion and sedimentation, so every instance of downcutting within the Cenozoic cannot be attributed to tectonic activity. Nevertheless, we believe structural movements, combined with pre-Ogallala volcanic activity to the west, were the primary determining factors in shaping the past and present landforms of western Nebraska.

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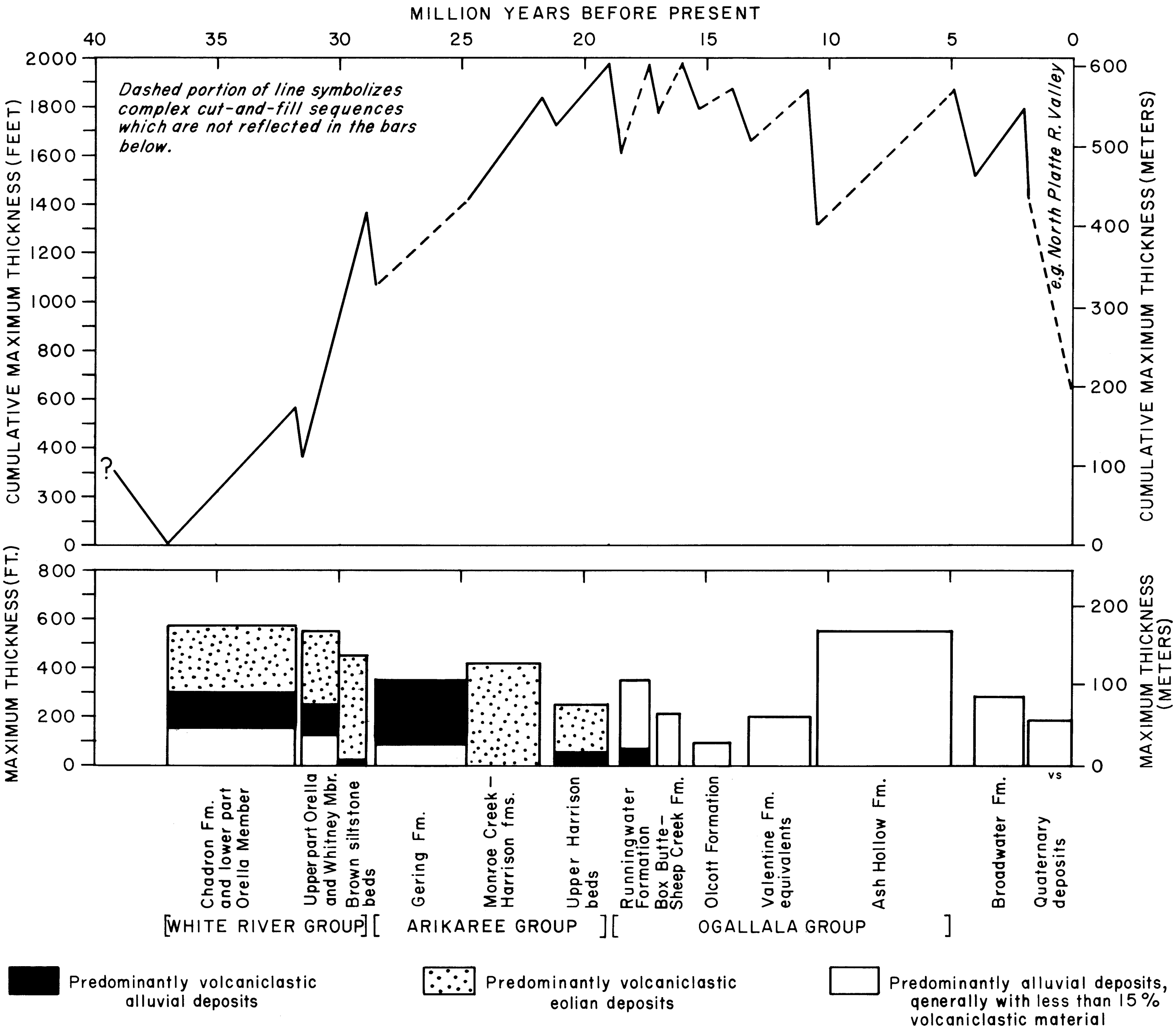

Figure 23. Time-maximum thickness and cumulative curve diagrams for the Cenozoic of the western part of the study area. Patterns of deposition are best shown by time-sediment volume graphs but sufficiently accurate volumes for the stratigraphic intervals used here are not known.

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